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A STUDY OF MASS FIRES AND CONFLAGRATIONS

64-3

By

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"It rejoiceth as a giant to run his course;
and there is nothing to be hid from the
heat thereof."

--Book of Common Prayer xix.1

What is the course of a conflagration? How fast will it spread and where and when will it stop? Can we describe in useful terms the mass fires that the fire services must combat after nuclear attack or natural disaster? These questions were posed by the Department of Defense, Office of Civil Defense, and studied by a research team from the U.S. Forest Service and United Research Services, Inc.

Although the Forest Service's 15-month study did not produce all the answers, the final report[1] contains information on the characteristics of conflagration fires in both urban and wildland areas that may be of value to fire chiefs and others responsible for fire defense planning.

1/ Chandler, C. C., Storey, T. G., and Tangren, C. D. Prediction of fire spread following nuclear explosions. Final report for Dept. of Defense, Office of Civil Defense, Contract No. OCD-OS-62-131. U. S. Forest Service Research Paper PSW-P5. Pacific SW. Forest & Range Expt. Sta., Berkeley, Calif. 1963.

OCD REVIEW NOTICE

This report has been reviewed in the Office of Civil Defense and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Office of Civil Defense.

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This note is our preliminary analysis and interpretation of the study conducted by the Forest Service for the Office of Civil Defense. As such, it represents our views only.

A review of

~~In~~ preparing this historical survey of conflagration fires, we reviewed the literature pertaining to fire spread,* ~~analyzed the~~ reports of 1,621 large wildland fires and 254 urban conflagrations ranging from the Great Chicago Fire of 1871 to the Coal Pier Fire of 1961,** ~~interviewed~~ more than 30 rural and city fire chiefs experienced in fighting conflagration fires,*** and ~~corresponded with~~ mass-fire experts in Canada, Australia, and Japan. ~~The major findings are summarized here.~~ were consulted.

* is presented.
** were analyzed
*** were interviewed

THE MASS FIRE PICTURE

Mass fires differ from the usual city or wildland fire in that large areas are actively burning at the same time. It has been widely asserted that mass fires resulting from nuclear explosions in the megaton range will cover hundreds of square miles and exhibit behavior characteristics and rates of spread never before experienced. A popular conception of conditions following nuclear attack is that of one gigantic holocaust.

Are these assertions reasonable? Admittedly mass fires following nuclear attack may be larger than any heretofore known. But there are several reasons for believing that the behavior and spread of such fires will be governed by the same factors, acting in the same way, as have affected large fires of the past. Theoretical considerations indicate that under typical fuel geometries, the violent winds characteristic of a firestorm can not penetrate beyond about half a mile into the fire area. Once a mass fire reaches a mile in diameter, its convection column reaches a height of 25,000 feet or more. Since about 70 percent of the mass of the atmosphere which supports fire is below this altitude, such a fire is exposed to the influence of all factors that will affect fires, no matter how large. To picture fire behavior in mass fires of this size, we can find several examples in urban areas and dozens in forest fires.

The most likely situation in the first few hours following a nuclear detonation is one in which several mass fires are scattered throughout a much larger fire area. Figure 1 shows part of such a fire in California. At the time the photograph was taken, the fire covered an area of almost 100 square miles. The mass fire in the foreground scales 1.4 miles across and 0.6 miles deep, all actively burning at the same time. A second area of mass fire can be seen in the right background, 11 miles away from the nearer portion of the fire.

Within any likely radius of ignition by a bomb, some areas will be free of kindling fuels, some areas will be shielded from thermal radiation by hills and buildings, and some areas will be screened by tree and brush foliage. Cloud cover will also affect the ignition patterns. Even within the area initially ignited, differences in fuel arrangement and exposure will influence the rate of fire buildup--some

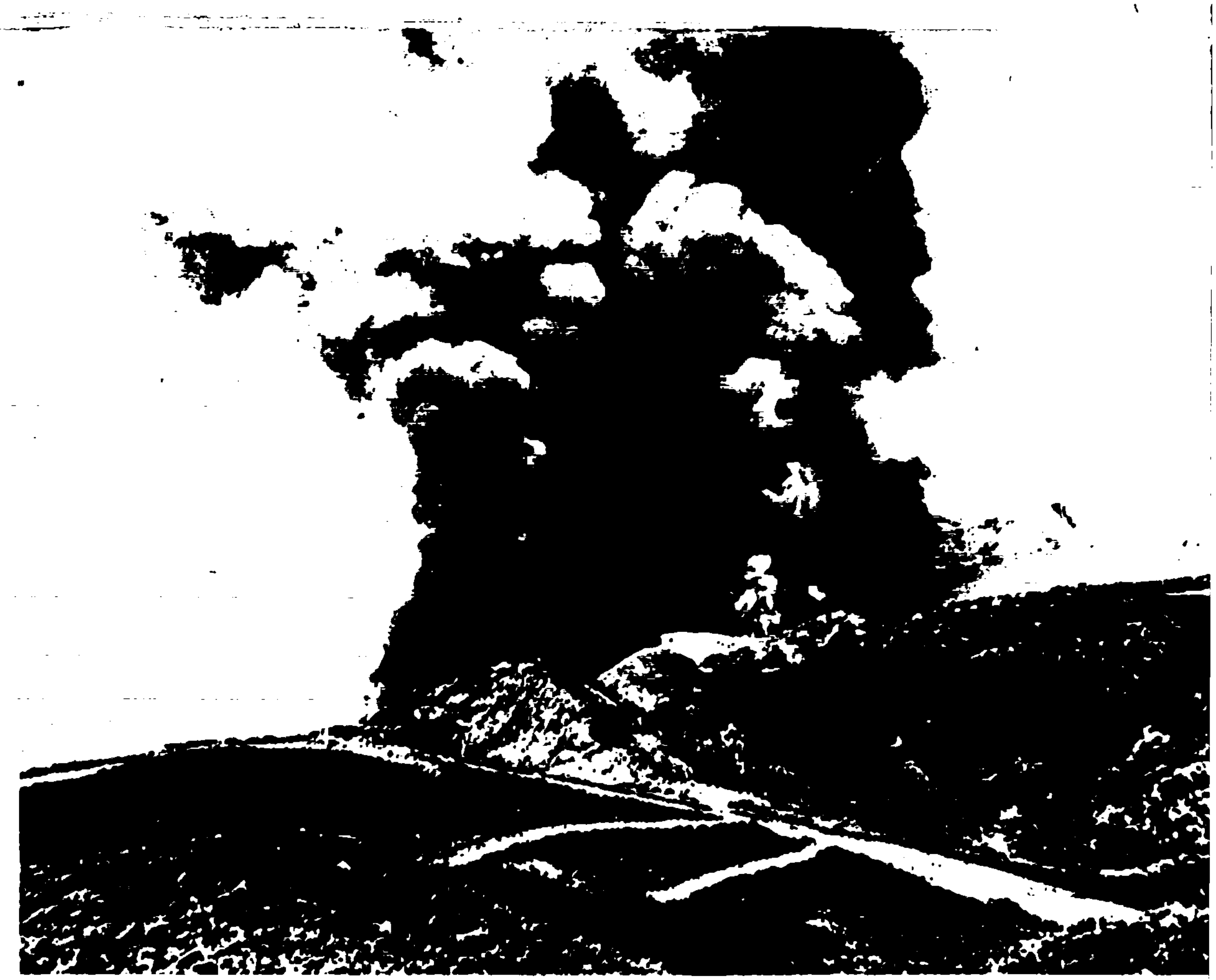

Figure 1.--Mass fires in portion of forest fire near San Juan Capistrano, December 17, 1958.

areas will have burned out before fires in other areas have merged to form a mass fire.

Mass fires in heavy concentrations of fuel can be expected to exhibit firestorm characteristics in the absence of strong natural winds. The firestorm is a special type of mass fire behavior characterized by violent indrafts around the burning area and centering on a rotating tornado-like column of flame and smoke. Firestorms gained public prominence during World War II when they followed saturation incendiary raids in some German and Japanese cities, but firestorms have also occurred occasionally in large peacetime fires of the past. In a firestorm, combustion is so intense that normal wind movement is blocked and air flows into the fire from all sides. But hurricane force winds are not uniform and continuous around the entire fire perimeter. Even at Hamburg, probably the most publicized firestorm in history, successful firefighting was possible at selected locations on the perimeter, and heavy smoke was reported in some places outside the fire area. Neither successful firefighting nor outward movement of smoke would be possible with continuous hurricane-force indrafts. Within the fire zone, however, there may be fire whirlwinds up to one-half mile in diameter and with indraft winds of 100 miles or more per hour. These will migrate through the mass fire zone and consume all combustible materials in their path. Within 3 to 4 hours the area will have been burned out; yet in this time the fire will have spread little beyond the area initially ignited.

Mass fires in the suburbs and in forested areas are likely to behave differently from those in areas of heavier fuel concentration. Only the most exceptional meteorological conditions will lead to firestorms. But if fuels are dry, conflagrations--that is, moving fire fronts--can be expected. When winds are strong, the fires will be spread by burning brands and the fire will advance in surges, traveling at rates up to 3 miles an hour in cities and wildlands alike for periods of an hour or less. In the absence of strong winds, spread will be slower but steadier, averaging from 1/10 to 1/2 mile per hour, depending on fuel, weather, and topography. At any given location, the fire will last only 1/2 to 2 hours.

Thus the total fire picture following a nuclear explosion is one of a countryside sprinkled with mass fires, some moving and some stationary, and interspersed with unburned and burned out areas. Except for firestorms in areas of dense fuel, this picture differs from that of such past conflagrations as Los Angeles' Bel Air Fire only in scope and not in kind.

Survival rates in this situation would be high everywhere except in the immediate firestorm areas; there, heat-resistant shelters with independent air supplies would be necessary for survival. It is notable that in the Hamburg firestorm there was no loss of life among those who took shelter in bunker shelters while an appreciable number of those in basement shelters were killed.

Although this picture is not a pleasant one, neither is it hopeless, and it is a far cry from the picture of hundreds of square miles of country instantly incinerated in one blast of flame. There appears to be no reason, from the fire standpoint, to act on the premise that civil defense measures are impossible or even impracticable.

DATA COLLECTED ON LARGE FIRES

So far, we have presented only a word picture of conditions in and around mass fire areas. When mathematical modeling is completed, modern computers can be used to analyze most local situations. Meanwhile, those responsible for fire defense may find some of the broader relations developed in the course of this study of material interest.

Using the data obtained from case histories supplemented by the judgment of experienced fire chiefs, we established:

1. The length of time various fuels might be expected to burn under selected weather conditions.

2. The conditions under which fires would be expected to exhibit no significant forward spread.

3. The free rate of spread of large fires under known conditions of weather, fuel, and topography.

Burning Times

Burning times were determined for three distinct burning regimes:

1. Violent burning time, representing the period of most active flaming at a given point on the fire perimeter.
2. Residual burning time, representing the period where glowing combustion is predominant but flames still occur nearby.
3. Potential threat time, representing the period during which a large fire might remain stationary yet be capable of resuming active spread if burning conditions change for the worse.

Table 1 shows the burning times for urban and wildland fuels under dry weather conditions with light winds.

Table 1.--Burning times for specified fuel types

Fuel type	Violent burning time	Residual burning time	Potential threat time
Grass	1-1/2 min.	1/2 min.	30 min.
Light brush (12 tons/acre)	2 min.	6 min.	16 hrs.
Medium brush (25 tons/acre)	6 min.	24 min.	36 hrs.
Heavy brush (40 tons/acre)	10 min.	70 min.	72 hrs.
Timber	24 min.	2-1/2 hrs.	7 days
Light residential	10 min.	12 min.	36 hrs.
Heavy residential	13 min.	20 min.	72 hrs.
Commercial	25 min.	1 hr.	7 days
Civic center and massive mfg.	55 min.	2 hrs.	2 months

"No Spread" Criteria

To prepare a mathematical model of fire spread in which fire-fighting is assumed to be ineffective, it is necessary to determine stopping rules; that is, the burning conditions under which fires could be expected to exhibit essentially no outward spread. Determining stopping rules was a relatively simple matter for forest fires, in which fire spread depends primarily on weather conditions.

Large fires in the following forest fuel types can be expected to show no measurable spread when any of the following conditions are met.

<u>All fuels</u>: More than 1 inch of snow on the ground at the nearest weather-reporting station.

<u>Grass</u>: Relative humidity is above 80 percent.

<u>Brush or hardwoods</u>: At least 0.1 inch of precipitation within the past 7 days AND--

Wind 0-3 m.p.h.; relative humidity 60 percent or higher, or

Wind 4-10 m.p.h.; relative humidity 75 percent or higher, or

Wind 11-25 m.p.h.; relative humidity 85 percent or higher.

<u>Conifer timber</u>: (a) 1 day or less since at least 0.25 inch of precipitation AND--

Wind 0-3 m.p.h.; relative humidity 50 percent or higher, or

Wind 4-10 m.p.h.; relative humidity 75 percent or higher, or

Wind 11-25 m.p.h.; relative humidity 85 percent or higher.

(b) Or, 2-3 days since at least 0.25 inch of precipitation AND--

Wind 0-3 m.p.h.; relative humidity 60 percent or higher, or

Wind 4-10 m.p.h.; relative humidity 80 percent or higher, or

Wind 11-25 m.p.h.; relative humidity 90 percent or higher.

(c) Or, 4-5 days since at least 0.25 inch of precipitation AND--

Wind 0-3 m.p.h.; relative humidity 80 percent or higher.

(d) Or, 6-7 days since at least 0.25 inch of precipitation AND--

Wind 0-3 m.p.h.; relative humidity 90 percent or higher.

In cities, fire spread depends more upon spacing between buildings and across streets and type of construction than upon weather changes. Consequently, it is not possible to devise hard-and-fast rules for fire spread in cities. Figure 2 shows the probability of fire spread for various values of fuel loading, exposure distance, and wind.

<u>Free Rates of Spread</u>

The major time and effort on this project was expended obtaining data on the rate of spread of conflagration fires burning under known conditions of fuels, topography, and weather. Spread rates were determined only if:

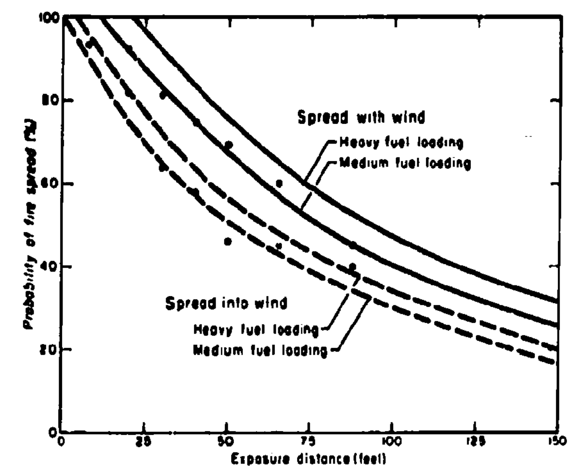

Figure 2.--Probability of urban fire spread across various exposure distances, by fuel type and wind direction.

1. The spread was essentially "free," that is, unaffected by fire-control action.
2. Linear spread rates could be determined between two known points and two known times.
3. Fuel and topography were known and weather measurements were obtainable from weather stations located sufficiently near the fire to have representative readings.

Although more than 90 percent of the fire reports studied failed to meet one or more of these criteria, we obtained 1,687 rates of spread from 364 burning periods of 133 fires. The final report contains complete data from all fires, including:

time and duration of spread
wind velocity and direction
temperature
relative humidity
fuel moisture
fuel type
length and degree of slope
profile of topography
type and rate of spread

Preliminary analysis of these data show that:

1. Fire spread, measured over periods of 6 hours or longer, is much slower than popularly assumed, and city fires spread at about the same rate as forest fires. Table 2 gives the mean rate of spread of the head, or fastest moving portion of urban and wildland fires.

2. Rates of spread are strongly time dependent. That is, the measured rate of spread depends on the length of time over which the

spread was measured. Table 3 shows rates of spread for various time periods for both urban and wildland fires.

3. Over long time periods, fires travel fastest over level ground. Measured over a 24-hour period, fires moving predominantly upslope averaged 0.04 m.p.h.; those moving downslope averaged 0.03 m.p.h.; those moving over level ground averaged 0.06 m.p.h.

4. On the average, the head of a conflagration fire moves at 3 times the rate of the flanks and 7 times as fast as the rear. In flat country with steady winds, fires tend to be highly elliptical in shape, but where topography is broken or winds are shifting the fire's outline is irregular.

Table 2.--Mean rate of fire spread in miles per hour, by fuel types

Fuel type	Rate of spread	
	Mean	Std. dev.
Cities	0.12	0.11
Wildlands	0.16	0.15

Table 3.--Mean rate of fire spread in miles per hour by time periods

Item	Rate when duration of spread (hours), was--					
	<1	1-2.9	3-5.9	6-11.9	12-23.9	24
Urban fires	0.86	0.21	0.16	0.15	0.06	--
Wildland fires	--	--	--	0.25	0.11	0.05